Appendix G
Climate variability detail

Much of the variability of the coastal waters and biota of British Columbia since 1970 can be related to changes in prevailing winds in winter. The years of 1970 to 2002 experienced significant, persistent, decadal regimes separated by surprisingly strong regime shifts. The strongest shifts appear to have been in 1976/77 and 1998/99, with another, perhaps weaker shift in 1989. Many of the oceanic and biological changes during one regime remained in place well into the following one. For example the cool subsurface waters formed at 120 meters depth during the 1999 to 2002 cool regime remained in place until early 2004. Some changes occurred with no apparent lag. An example of this are coho salmon indicators in the Strait of Georgia, which have oscillated in phase with temperature regimes. All wild and hatchery indicators [of coho] in the Georgia Basin have followed the same trend: minimum survivals in about 1998 after a relatively steady decadal decline followed by a slight improvement until 2001 and a decrease since. In general, warmer regimes are associated with stronger winds from the south along the coast, lower surface nutrient levels, stronger coastal flow to the north, increasing numbers and percentage of southern species of plankton, and of fish such as sardines and hake, and lower marine survival for Pacific salmon at the southern limit of their range. Cooler winds reverse these trends. (Pacific Region 2003 State of the Ocean, Department of Fisheries and Oceans Canada, 2004).

Many oceanic features and biological species responded in 2003 to these past changes in winter winds and surface ocean temperatures in the Canadian waters. Specific examples of responding features and species are listed below. The descriptions below are taken verbatim from the DFO report itself, referenced in the Section 8.

"Coastal water levels were well above normal in the warm 1990s, lower than normal in 1999 to 2002, and a bit higher again in 2003.

The **North Pacific Current** flowed more toward the north in late 2002 and early 2003, coinciding with the weak El Niño. It normally flows eastward along 40°N toward North America. By early 2003, perhaps when El Niño-like winds abated in the Gulf of Alaska, it returned to a more normal course.

Coastal temperatures sampled at light stations were above normal during the 2002-2003 winter along the west coast of Vancouver Island, and normal during the rest of 2003. Strait of Georgia and northern BC temperatures were warmer in 2003 than during the previous 4 cool years.

Ocean surface waters of the Canadian Exclusive Economic Zone (200-mile limit) were also warmer in 2003 than in previous three to four years. However, subsurface waters from 100 to 200 metres depth carried cooler temperatures from the 1999 to 2002 cold regime because the ocean surface heating requires more than one year to penetrate below 100 metres.

Alongshore current in 2003 on the Vancouver Island continental shelf saw a return to near 1990-96 average northward flow since a gradual but dramatic shift to a more equator-ward component that began in 2000. Both shifts are likely due to winter wind patterns noted above.

Phytoplankton growth in spring of 2003 along the southwest coast of Vancouver Island was lower than observed by satellite in the preceding four cool years, and closer to the low growth observed in the spring of 1998, the previous warm year.

Deep-sea zooplankton biomass during spring (May-June) was lower in 2003 than in the previous two colder years by about a factor of 2, based on preliminary analysis of a few samples. (When surface waters are cool, nutrient levels are often higher.) For June to August 2003 it appears that subtropical species extended further north *and* boreal species were still doing well throughout the region.

West Coast Vancouver Island zooplankton showed effects of the 2002/2003 El Niño. Southern species increased in biomass, following an increase in northern species during the 1999-2002 years of cool coastal waters. For most species, the strongest anomalies were in spring and early summer of 2003, and had returned to near-zero by early autumn.

Barkley Sound euphausiid (*T. spinifera*) larvae and adults biomasses in 2003 were the lowest in the time series; adult biomass was at least 10 times lower than in most other years and 100 times less than in 2000.

Pacific hake were also found farther north in 2003, due perhaps to warmer waters in the continental shelf than 1999 to 2002, and perhaps to the continued, normal, northward spread of an individual year-class of hake. Hake biomass increased in 2003 due to the growth of individuals in the 1999 year-class that dominates the population along the West Coast.

California tonguefish (*Symphurus atricauda*) were observed in May 2003 in Barkley Sound, the most northerly occurrence ever reported for this species. This is consistent with warmer waters and weak El Niño in 2002-2003.

West Coast Vancouver Island eulachon index increased during the 1999-2002 cool years, but declined slightly in warmer 2003.

Herring year classes of the cool years of 2000 and 2001 are large on the west coast of Vancouver Island, and should result in improved recruitment to the stock in the year 2003 and 2004. The warmer waters of 2003 might impact herring stocks by bringing in more predatory hake.

Sardines were scarce in the 2003 trawl survey off Vancouver Island except in the south and some concentrations at the mouth of the inlets. Their numbers had increased during warm years of the late 1990s, but decreased during the 1999-2002 cool period. The 2003 warming was likely too short duration and too recent to abate this decline.

Juvenile Coho growth conditions off south-western British Columbia were lower in 2002 to 2003 than in 2001 to 2002, but similar to conditions seen during the three preceding cool years. Generally, coho juveniles in this region are healthier in colder years, and their poorer conditions following the warmer 2002-2003 winter support this hypothesis.

Pink salmon returned in record high numbers to the Fraser River in 2001 and estimated high numbers in 2003. (They entered the ocean in 2000 and 2002.)

Sockeye salmon returns to the Fraser River were slightly above average in 2002 and near average in 2003. Survival was slightly below average in both years.

Pacific herring had the largest biomass in 2003 in the Strait of Georgia since 1955. These three adult stocks likely responded well to the cool regime that began in 1999. The warm winter of 2002-2003 was too recent to impact present adult stocks.

Cassin's auklets fledgling production in 2003 was higher in 2003 than during the warm years in the 1990s on Triangle Island off northern Vancouver Island, but lower than during the cool years of 1999- 2002. This production likely varies as the supply of prey, mainly **Pacific sandlance**, which itself varies in biomass with changes in local temperatures, nutrients and plankton biomass."

Other Aspects of Climate change

Working Hypothesis

Regional expressions of global climate change may affect juvenile Chinook and chum salmon as a result of sea level rise, warmer water temperatures and changes in precipitation.

Effects on Ecosystem Processes and Habitat Characteristics

Researchers affiliated with Pacific Northwest Coastal Ecosystem Regional Study (PNCERS) suggests that a likely possible trend in climate change is for the Pacific Decadal Oscillation to have more El Nino-dominated years and fewer La Nina-dominated years as global sea surface temperatures rise. One such affect of these changes on Puget Sound's nearshore is relative sea level rise. Many nearshore habitats are arranged on the landscape according to their elevation relative to mean sea level. The amount of inundation, dessication, wave scour, substrate type and light penetration and other abiotic factors often determine the distribution patterns of plants from high intertidal fresh and saltmarsh grasses and shrubs to subtidal marine macroalgae. It is likely that some of the loss of certain plant species from an area or shifting of the location of certain species is as a result of relative sea level rise attributed to global climate change and land subsidence. The localized effects of this shift are variable. South Puget Sound, because it is subsiding will likely experience more severe relative sea level rise throughout the next 100 years than other areas.

If relative sea level rise occurs slowly and there are no barriers to plant migration on the upland edge of the continuum, nearshore habitats will likely be able to keep pace. However, sea level rise is accelerating compared to last century and the armoring of the upland portions of many of Puget Sound's shorelines may prevent this migration. The Intergovernmental Panel on Climate Change estimates that overall sea level rise will be at a rate of 2.0 to 8.6 mm/yr over the next century as compared to 1.0 to 2.5 mm observed over the previous decade (UW Climate Impacts Group). The future effects of other climate change parameters such as rainfall and wind field changes on nearshore habitats and salmon are not well understood at this time.

River Deltas

Because deltaic wetlands and lowlands were created by the deposition of river sediments, these lands are generally within a few meters of sea level and hence vulnerable to inundation, erosion, and flooding. Under natural conditions the sediment washing down the river could enable at least a significant fraction of the typical delta to keep pace with sea level rise. Human activities in many deltas, however, have disabled the natural ability of deltas to create land. Over the last 150 years, people have erected dikes and river levees to prevent flooding from storm and river surges. As a result, the annual floods no longer overflow the riverbanks, and as sea level rises, it has left the adjacent land below sea water level, necessitating more coastal defense to prevent the land from being inundated (Titus 1990).

Tidal marshes

The standard method for evaluating whether sea level rise is threatening tidal marshes is through comparison of the accretion rate of marshes with the relative rise rate of the sea. Using Cs137 as a marker, Thom *et al*. (2001) found that most marshes are presently keeping pace with sea level rise in the Pacific Northwest. Perhaps the most vulnerable marshes are those in central and lower Puget Sound where relative sea level rise exceeds the global rate. The marshes depend on a steady supply of sediments and nutrients to support accretion. If these were cut off through shoreline armoring and watershed development, the marshes in southern Puget Sound would predictably succumb to rising sea level (Thom *et al*. 2001). Many marshes in the Puget Sound region have been diked, drained, and converted to farmland during the last century. Sea level rise could gradually inundate the remaining tidal flats. Over half of these could be lost under a 1-3 foot rise in sea level (EPA 1997).

Eelgrass

There is little doubt that all of the estuarine and marine plants respond in a similar manner physiologically to temperature. Submerged plants such as eelgrass and kelp (*Nereocystis luetkeana*), may be the most susceptible to warmer conditions. Our experiments with eelgrass (*Zostera marina*) indicate that Pacific Northwest estuarine system processes are vulnerable to temperature variations (Thom *et al.* 2001).

Under a warmer climate, water temperatures may be higher on average, which may cause greater warming in summer and further stress on the plants. Eelgrass ranges into warmer regions south of the Pacific Northwest. However, the genetics and phenology of these warm water populations probably differs substantially from those in the Northwest. We do not expect elimination of eelgrass from the Pacific Northwest with a warming climate unless the warming occurs so rapidly as to not allow for northward expansion of these southern populations or adaptation of local populations (Thom *et al.* 2001).

Water quality

Newton *et al* (2003) demonstrate that changes in river inflows to Puget Sound affect the circulation of water into and out of the region. When river flows into Puget Sound are reduced, the density structure of the water column is reduced, as is the exchange of waters with the Pacific Ocean (Newton *et al.* 2003).

Puget Sound streams with headwaters at high elevations, especially in the Cascades and Olympics, are affected by winter snow and spring snowmelt, but lower elevation streams are dominated by winter rainfall. The seasonal pattern of flow in most streams would be highly susceptible to warmer temperatures. Runoff peaks would occur earlier in the year. The reduced summer and fall flows that would accompany a warmer climate almost certainly would result in degraded water quality. In addition, increased snowmelt could increase winter flooding for some streams (EPA 1997). The effect of these runoff changes will also affect salinity in the shallow water corridors used by juvenile salmon for migration.

Effects on Salmon

Climate is an important process control. While salmon are highly adaptable to changing conditions, the end result of some climate-related large-scale disturbances may alter the nearshore ecosystem in ways that will not recover (K. Fresh, NOAA-Fisheries, personal communication). For example, sea level rise coupled with upland infrastructure prevents the landward migration of salt marshes (Titus 1990).

Beamish (1995) found significant correlations between climate changes and fish populations for many fish species, including salmonids, Pacific herring, Pacific cod, walleye pollock, and species of zooplankton upon which many fish depend for food. As models of these variations improve to the point of becoming predictive, hatchery and harvest managers may need to make adjustments to their management plans. The regime shifts are also often accompanied by changes in the geographic distribution of marine species.

Because of the strength of ocean conditions on salmon viability throughout its life cycle, it is difficult to predict the ultimate response salmon will have to improvements or degradation of habitat features.